World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Spatial variations of aquatic macroinvertebrates assemblages in response to anthropogenic activities in Comoé River (middle catchment, Bettié Côte d'Ivoire)

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World Journal of Advanced Research and Reviews, 2025, 27(01), 1004-1020

Publication history: Received on 30 May 2025; revised on 05 July 2025; accepted on 08 July 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.27.1.2565

Abstract

This study aimed to assess the impact of anthropogenic disturbances on aquatic macroinvertebrates assemblages in the middle catchment of the Comoé River and its tributary, the Manzan River. Five sampling stations were selected based on varying levels of human-induced perturbations and monitored over four field campaigns from March 2021 to March 2022. Environmental variables such as temperature (°C), pH, conductivity (µS/cm), water depth (m), dissolved oxygen (mg/L), turbidity (NTU), ammonium (mg/L), nitrite (mg/L), nitrate (mg/L), phosphate (mg/L) and suspended matter (mg/l) were recorded across stations in order to have a closer approach of species distribution according to abiotic variables.

In total, 8,547 individuals representing 6 classes, 15 orders, 54 families and 103 taxa were identified. Insects, particularly Heteroptera and Ephemeroptera, were dominant respectively in Manzan and M'Basso stations. Taxonomic richness was highest at Pont Bettie and lowest at Manzan, where diversity was also poor (Shannon-Weaver index = 1.5). The proportion of pollution-sensitive taxa (EPT) was highest in M'Basso station (59.77%) and lowest in Manzan station (6.27%). A focused principal component analysis (FPCA) showed that environmental variables such as pH, dissolved oxygen, turbidity, conductivity and suspended matter, influenced aquatic macroinvertebrates.

Keywords: Aquatic macroinvertebrates assemblage; Anthropogenic disturbances; Environmental variables; FPCA; EPT taxa

1. Introduction

Freshwater ecosystems faced multiple anthropogenic pressures ranging from agriculture, deforestation, mining to urban expansion and infrastructure development, all of which can severely disrupt ecological integrity of rivers and streams [1, 2, 3]. Land use not only exerts direct influence on stream ecosystems but also interacts with other stressors such as climate change [4], invasive species [5], and river regulation by dams [6], leading to compounded ecological consequences.

Côte d'Ivoire has experienced alarming rates of deforestation, with forest cover declining from 7.9 million hectares in 1990 to only 3.4 million hectares in 2015 [7]. This deforestation, particularly acute in south-west and middle-eastern parts of the country, is largely attributed to agriculture and logging, leading to loss of biodiversity and degradation of aquatic systems [8, 9]. For instance, rapid expansion of rubber cultivation in southern Côte d'Ivoire, which grew from 200,000 ha in 2008 to over 300,000 ha in 2012 [10], has contributed to widespread deforestation and associated aquatic impacts [11, 12]. Agricultural practices including cocoa, banana and rubber plantations, are known to contribute significantly to soil erosion, nutrient enrichment, sedimentation and increased pesticide input into water bodies ([13,

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14, 15]. Agricultural impacts are further exacerbated by unregulated artisanal gold mining, a dominant economic activity in many rural regions of the country.

Artisanal and small-scale gold mining, in particular, has become a major ecological threat, employing low-technology methods involving deforestation, soil excavation and the use of hazardous chemicals such as mercury and cyanide for mineral extraction [16, 17, 18]. These practices generate significant amounts of tailings and chemical waste, which are discharged directly into water bodies, resulting in acid mine drainage, elevated heavy metal concentrations and habitat degradation [19, 20, 21]. In addition, this practice affects stream water quality through increased pesticide, turbidity, sedimentation, nutrient loading and altered thermal regimes, all of which influence aquatic life. Indeed, the disturbances caused by anthropogenic activities on aquatic ecosystems directly impact biological communities present [22, 23]. The phenomena affect many main water courses in Côte d'Ivoire. For example, a recent expansion of artisanal and large-scale gold mining occurs in Marahoué river, a tributary of Bandama River, one of the four main river system in the country [24] with significant impact directly on the biological communities [22, 23]. As this phenomenon affect all water courses in the country, there is a need to understand its impact on aquatic communities in general and particularly on macroinvertebrates.

Aquatic macroinvertebrates, which are widely used for biomonitoring aquatic ecosystems, are particularly sensitive to environmental pollution due to their stationary nature and varying levels of tolerance to contaminants [25, 26]. Moreover, macroinvertebrates contribute significantly to ecosystem functioning as decomposers and primary consumers [27, 28]. Their structural composition offers critical insight into the ecological status of freshwater bodies, particularly in regions where other monitoring tools may be limited [29, 30]. Despite their ecological relevance, studies on macroinvertebrate assemblages in Côte d'Ivoire remain limited in scope and spatial coverage. While research has been conducted in the lower part [31, 32] and in the middle course of Comoé River [33], the middle catchment and its tributary, Manzan River in the Bettié department, where human pressures are particularly acute has received little scientific attention. This lack of data poses challenges for informed management and conservation of aquatic ecosystems in the region. Given the importance of this area for both biodiversity and human livelihoods, understanding spatial variations in aquatic macroinvertebrates communities in response to land-use changes and artisanal gold mining is important.

This study seeks to address knowledge gap by investigating spatial patterns of aquatic macroinvertebrate assemblages in middle catchment of Comoe River and its tributary (Manzan River). The objectives are to (i) characterize environmental variables quality of water in study area, (ii) determine structure and abundance of macroinvertebrates, and (iii) identify how environmental variables affect macroinvertebrates communities.

2. Material and methods

2.1. Study area and sampling station

This study was carried out from March 2021 to March 2022 in the Bettié department, located in Eastern part of Côte d'Ivoire between latitude 6°04' North and longitude 3°24' West.

Table 1 Coordinates and levels of activities identified at each sampling station in the middle catchment of Comoé River

Sampling stations	Geographic coordinates		Land use and mining activities	Substrata of soil (%)	Streams color	Vegetation cover (%)
	Latitude	Longitude				
M'Basso	06.24892°	-003.45189°	Rubber plantation, Maize fields	Gravel (10%) Boulders (85%) Sand (5%)	Clear	5
Manzan	06.24887°	-003.45186°	Rubber plantation, Banana plantation, Cocoa plantation, gold mining activities (mineral drainage)	Clay (75%) Silt (10%) Boulders (1%)	Very Brown	70

Yèrè Yèrè1	06.24 566°	- 003.4 4944°	Village, Rubber plantation, small gold mining activities behind Yèrè Yèrè1 Village	Clay (58%) Sable (35%) Boulders (10%)	Brown	25
Abradinou	06.17 935°	- 003.4 6151°	Village, Rubber plantation, Banana plantation, Sand Removal	Clay (30%) Sand (55%) Silt (10%)	brown	15
Pont Bettie	06.06 382°	- 003.4 2307°	Bettie city, Rubber plantation, Banana plantation, Rubber tree nursery, Water treatment station, Cocoa plantation	Clay (30%) Silt (20%) Gravel (15%)	Brown (the first three sampling)	10

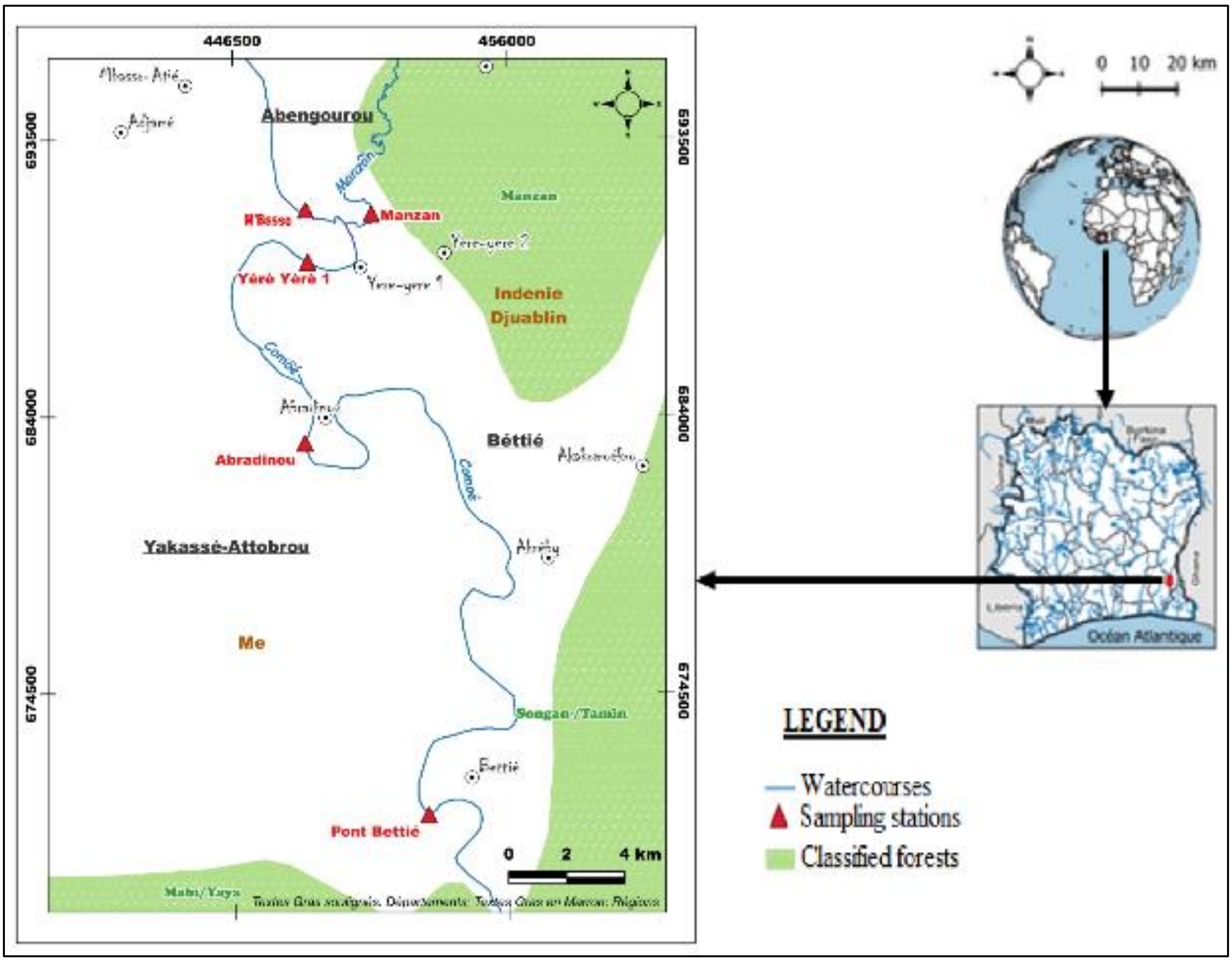


Figure 1 Location of the study area showing sampling stations

The vegetation originally characterized by the dense semi-deciduous humid forest [34] was now replaced by 70% rubber plantation. The main water course is Comoé River and its tributary, Manzan River. Several activities occurred alongside those rivers (Table 1).

The study site is characterized by four climatic seasons: two rainy seasons (A long rainy season and a short rainy season respectively from April to July and October to November) and two dry seasons (A long dry season and a short dry season respectively from December to Mach and August to September) [35].

Five sampling stations were selected based on accessibility and level of perturbation identified: one (1) before the confluence in the stream: unperturbed (M'Basso station); another one (1) on the tributary with illegal gold mining activity (Manzan station), one in the confluence zone (Yèrè Yèrè1 station), one near a sand removal site (Abradinou station) and the last in the downstream polluted with waste water from Bettie city (Pont Bettie station) (Fig 1).

2.2. Environmental variables sampling

A total of 11 environmental variables were selected for this study: water temperature (°C), pH, conductivity (µS/cm), water depth (m), dissolved oxygen (mg/L), turbidity (NTU), ammonium (mg/L), nitrite (mg/L), nitrate (mg/L), phosphate (mg/L) and suspended matter (mg/L). A multiparameter device (LOVIBOND SensoDirect 150) was used in situ to measure water temperature, dissolved oxygen, pH and conductivity. Water samples were collected in 1L bottle and analysed for turbidity, ammonium, nitrite, nitrate, phosphate and suspended matter according to APHA [36] methods.

2.3. Aquatic macroinvertebrates sampling and identification

Aquatic macroinvertebrates sampling methods were designed to collect both quantitative and semi-quantitative samples because this could provide reliable information on the macroinvertebrate communities [37]. Quantitative samples were collected using a Van Veen grab (0.05 m^2) for sediments. Contents of the grab were washed through a sieve of 1 mm mesh size. Benthic macroinvertebrates recovered from the sieve were preserved with 70% alcohol for further analysis. Semi-quantitative samples were collected using kick net (250 µm mesh, 50 cm length) in all habitat types. We also used artificial substrates filled with stones sieved between 3 and 8 cm and organic matter such as wood. Substrates were settled near the riverbank and were removed after 45 days of colonization and transferred to a 1 mm sieve and washed. Samples from all sampling devices were fixed with 70% alcohol. In the laboratory, organisms were sorted and identified as possible to species level using appropriate identifications keys [38, 39, 40, 41, 42, 43, 44, 45].

2.4. Data analysis

Various community characteristics of macroinvertebrates were estimated including diversity [46, 47], richness [48], and evenness [49]. For the assessment of macroinvertebrate community, taxa richness was estimated using a rarefaction method described by Gotelli and Ellison [50]. Structure of macroinvertebrates communities was evaluated using, Shannon-Weiner index (H') [46, 47] and Pielou Evenness index (E'). Shannon-Weaver and Pielou Evenness indexes were calculated using R (package Vegan). Moreover, taxa richness was rarefied to eliminate any bias related to differences in abundances between samples [51, 52]. Calculations were performed using the lowest abundance (four individuals for this study) found in all stations as the target number of individuals [53].

We assessed the Ephemeroptera, Plecoptera and Trichoptera index (EPT) as an indicator of good quality of sites [54].

Frequency (F) of taxa was calculated at all sampling stations. F is the percentage of samples in which each taxon occurred. It was calculated according to Dajoz [55] to gives some information on the number of taxa frequently met in each station without any indication on their quantitative importance [56, 57].

Focused Principal Component Analysis (FPCA) was used to show influence of environmental variables studied on the most abundant taxa (relative abundance of taxa representing 2% of total abundance of aquatic macroinvertebrates) [58]. FPCA revealed exact correlations between variables, providing insight into the relationships between macroinvertebrates and their environment [59].

We used Kruskal-Wallis test followed by Mann-Whitney test to evaluate significance of spatial variations in environmental variables and diversity indices. All analyses were conducted using the R 4.4.2 software within RStudio, "vegan", and "psy" packages (Core, 2024) [60, 61].

3. Results

3.1. Environmental variables characteristics

Sampled stations represented a broad range of water depth (0.4-7.6 m), water temperature (24.8-31.9 °C), conductivity (50-180 µS/cm), pH (4.45-9.31), dissolved oxygen (0.1-8.1 mg/L), turbidity (11.7-2355 NTU), suspended matter (3-1372 mg/L). Concentrations of nutriment were low with ammonium ranged from 0.0011 to 2.5 mg/L. Concentration of nitrite varied from 0.003 to 2.43 mg/L, concentrations of nitrate were from 0.012 to 12.52 mg/L and, concentrations of phosphate were ranged from 0.2 to 7.1 mg/L. However, median values of environmental variables of stream stations are shown in Table 2. Median water depth values were significantly lower deep from upstream (M'Basso station) to downstream (Pont Bettié station) (Mann-Whitney $p < 0.05$). Dissolved oxygen values showed a significant difference between M'Basso station and Manzan station, Yèrè Yèrè1 station and Abradinou station (Mann-Whitney $p< 0.05$). Turbidity values were significantly highest in Manzan station than all stations (Mann-Whitney $p< 0.05$). However, conductivity values showed a significant difference between Manzan station and all stations (Mann-Whitney $p< 0.05$) excepted Pont Bettié station (Mann-Whitney $p>0.05$). According to suspended matter, median values were significantly high in Manzan station than all stations and a significant difference between M'Basso station and Abradinou station. Indeed, environmental variables such as water temperature, pH, nitrite, nitrate, ammonium and, phosphate did not show significant difference between sampling stations (Kruskal-Wallis $p>0.05$) (Table 2).

Table 2 Minimum, maximum, and median values of the environmental variables in the middle catchment area of Comoe River

		Environmental variables										
Stations		**Dp (m)**	**Tp (°C)**	**Cd (µS/cm)**	**pH**	**DO (mg/L)**	**Tb (NTU)**	**Am (mg/L)**	**Nti (mg/L)**	**Nta (mg/L)**	**Pho (mg/L)**	**SM (mg/L)**
MB	Min.	0.4	27.3	50	6.3	3.7	11.7	0.01	0.009	0.012	0.39	5
	Max.	2.5	30	72	9.31	8.1	77	0.45	0.083	0.1	1.2	32
	Med.	0.95^{a}	29.25^{a}	62.5^{a}	7.48^{a}	5.2^{a}	27.5^{a}	0.0205^{a}	0.052^{a}	0.0205^{a}	0.515^{a}	20.5^{a}
MA	Min.	1.1	24.8	99	4.45	0.1	997	0.45	0.03	0.13	0.2	691
	Max.	4.4	28.6	180	6.4	1.3	2355	2.5	2.43	12.52	7.1	1372
	Med.	2.25^{ab}	28.2^{a}	116^{b}	5.45^{a}	0.65^{b}	1306^{b}	2.3^{a}	0.44^{a}	6.115^{a}	2.55^{a}	764.5^{b}
YY1	Min.	1.9	25	74	4.67	0.3	42	0.0012	0.003	0.014	0.19	6
	Max.	5.7	31.6	87	7.4	1.7	262	1	0.25	8.98	0.5	249
	Med.	2.55^{ab}	28.05^{a}	84^{c}	6.8^{a}	1.3^{b}	196.5^{a}	0.095^{a}	0.014^{a}	0.9535^{a}	0.375^{a}	46^{ac}
AB	Min.	2	27.9	70	4.51	0.2	49	0.01	0.009	0.012	0.4	51
	Max.	5.4	31.1	82	7.2	1.7	908	0.47	0.091	6.39	1.31	522
	Med.	3.85^{ab}	29.9^{a}	80^{ac}	4.98^{a}	0.4^{b}	159^{a}	0.11^{a}	0.0405^{a}	0.102^{a}	0.59^{a}	75.5^{c}
PB	Min.	4.3	25.7	71	4.54	0.4	25	0.0011	0.007	0.016	0.3	8
	Max.	7.6	29.6	110	7.9	4.5	329	1.4	0.039	0.9	3.2	200
	Med.	5.75^{b}	28.7^{a}	80.55^{abc}	5.085^{a}	1.4^{ab}	89.2^{a}	0.09^{a}	0.0185^{a}	0.02005^{a}	1.69^{a}	32.5^{ac}

MB: M'Basso; MA: Manzan; YY1: Yèrè Yèrè1; AB: Abradinou; PB: Pont Bettié; Min: Minimum; Max: Maximum; Med: Median; pH: potential of hydrogen; Dp: water depth; Tp: water temperature; Cd: conductivity; DO: dissolved oxygen; Tb: turbidity; Am: ammonium; Nti: nitrite; Nta: nitrate; Pho: phosphate; SM: suspended matter.

Table 2 Taxonomic list of aquatic macroinvertebrates collected from the sampling stations in the middle catchment of Comoé River

				Stations					
Class	**Order**	**Family**	**Taxa**	**MB**	**MA**	**YY1**	**AB**	**PB**	**F(%)**
Clitellata	Ind.	Ind.	Ind.	+		+	+	+	**
Gastropoda	Basommatophora	Lymnaeidae	*Lymnaea natalensis*		+				*
		Planorbidae	*Biomphalaria pfeifferi*	+	+	+	+	+	***
			Bulinus globosus	+	+	+	+	+	***
			Bulinus troncatus	+	+	+	+	+	***
			Bulinus sp.	+		+		+	**

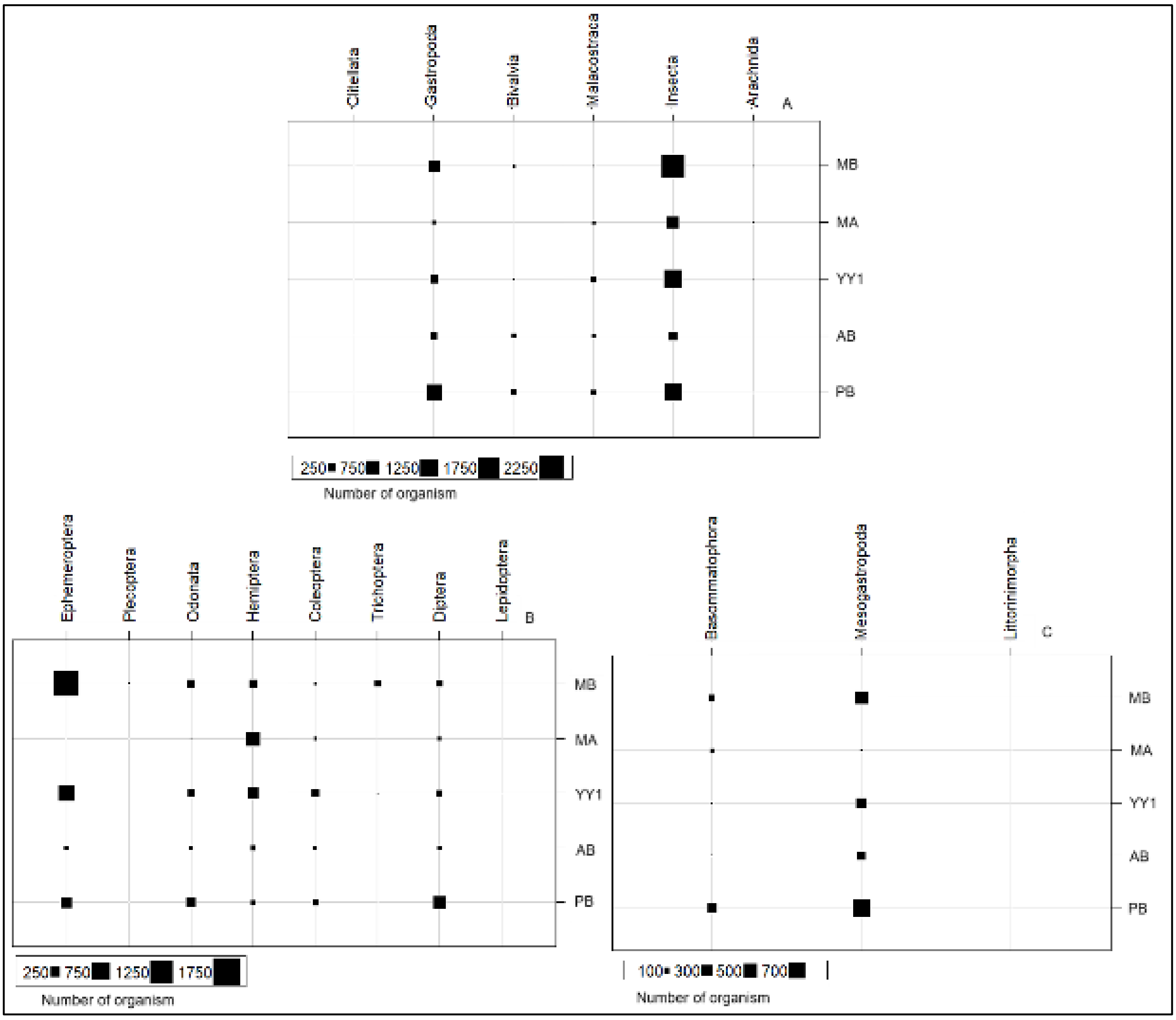
			Indoplanorbis exustus	+			+	+	**
	Mesogastropoda	Ampullariidae	*Lanistes varicus*	+	+	+	+	+	***
			Pila africana	+	+			+	**
		Paludomidae	*Cleopatra* sp.	+		+	+	+	***
		Thiaridae	*Melanoides tuberculata*	+	+		+	+	**
	Littorinimorpha	Bithyniidae	*Gabbiiella africana*		+			+	*
Bivalvia	Myoida	Corbulidae	*Corbula* sp.	+		+	+	+	***
	Unionida	Unionidae	*Coelatura aegyptiaca*	+		+	+	+	***
Malacostraca	Decapoda	Atyidae	*Caridina africana*	+	+	+	+	+	***
		Palaemonidae	*Macrobrachium raridens*		+	+	+	+	**
			Macrobrachium sollaudii	+	+	+	+	+	***
			Macrobrachium sp.	+	+	+	+	+	***
		Potamonautidae	*Potamonautes ecorssei*	+	+	+	+	+	***
Insecta	Ephemeroptera	Baetidae	*Baetis* sp.	+	+	+	+	+	***
			Cleon sp.	+	+	+		+	***
			Labiobaetis sp.	+	+	+	+	+	***
			Procleon sp.	+		+	+	+	***
		Caenidae	*Caenis* sp.	+	+	+	+		***
		Ephemeridae	*Eatonica* sp.	+				+	**
			Ephemerella sp.	+					*
		Heptageniidae	*Afronurus* sp.	+					*
			Dacnogenia sp.	+					*
			Ecdyonurus sp.	+					*
			Electrogena sp.	+					*
			Heptagenia sp.	+					*
		Leptophlebiidae	*Adenophlebiodes* sp.	+					*
			Choroterpes sp.	+					*
			Epeorus sp.	+					*
			Paraleptophlebia sp.	+					*
			Thraulus sp.	+					*

				Stations					
Class	**Order**	**Family**	**Taxa**	**MB**	**MA**	**YY1**	**AB**	**PB**	**F(%)**
Insecta	Plecoptera	Perlidae	*Perla* sp.	+					*
	Odonata	Calopterygidae	*Phaon* sp.	+				+	*
			Pseudagrion sp.	+	+	+	+	+	***
		Corduliidae	*Phyllomacromia* sp.	+		+		+	**
		Gomphidae	*Ceratogomphus* sp.					+	*
			Ictinogomphus sp.		+	+		+	*

			Lestinogomphus sp.				+	+	**
			Neurogomphus sp.	+		+	+	+	**
			Phyllogomphus sp.	+	+	+	+	+	***
		Lestidae	*Lestes* sp.	+				+	**
		Libellulidae	*Brachytemis* sp.	+		+	+	+	***
			Chalcostephia sp.	+			+	+	**
			Olpogastra sp.	+	+	+	+	+	***
			Trithemis sp.	+	+	+		+	**
			Zygonyx sp.			+			*
		Synlestidae	*Chlorolestes* sp.				+	+	*
	Heteroptera	Belostomatidae	*Diplonychus* sp.	+	+	+	+	+	***
		Corixidae	*Micronecta* sp.					+	*
		Gerridae	*Aquarius* sp.	+	+	+	+	+	***
			Eurymetra sp.	+	+	+	+	+	***
			Gerris sp.	+	+	+	+		**
			Limnogonus sp.			+	+		*
			Neogerris sp.	+		+			*
			Rhagadotarsus sp.		+				*
		Hydrometridae	*Hydrometra* sp.	+		+	+	+	***
		Nepidae	*Ranatra linearis*	+	+	+	+	+	***
		Pleidae	*Plea* sp.		+				*
		Mesoveliidae	*Mesovelia* sp		+	+		+	**
		Naucoridae	*Macrocoris* sp.		+				*
			Naucoris sp.		+			+	*
		Notonectidae	*Anisops* sp.	+	+	+	+	+	***
			Enithares sp.	+	+	+		+	**
			Notonecta sp.	+	+	+	+	+	***
			Nychia sp.			+	+		*
		Veliidae	*Microvelia* sp.	+		+	+	+	**
			Ocellovelia sp.		+				*
			Rhagovelia sp.	+	+	+		+	***
	Coleoptera	Dytiscidae	*Bidessus* sp.				+	+	*
			Graphoderus sp.			+			*
			Hydaticus sp.	+					*
			Hydrovatus sp.		+	+	+	+	**
			Ilybius sp.	+				+	*
			Laccophilus sp.			+		+	*
				Stations					

Class	**Order**	**Family**	**Taxa**	**MB**	**MA**	**YY1**	**AB**	**PB**	**F(%)**
Insecta	Coleoptera	Elmidae	*Dupophilus* sp.	+					*
			Elmis sp.	+				+	*
			Limnius sp.	+	+	+	+	+	**
			Normandia sp.	+		+	+	+	**
			Potamodytes sp.			+			*
			Potamophilus sp.	+					*
		Gyrinidae	*Orectogyrus* sp.		+	+		+	***
		Hydrophilidae	*Enochrus* sp.			+	+	+	*
		Noteridae	*Hydrocanthus* sp.		+		+	+	*
		Spercheidae	*Spercheus* sp.		+				*
	Trichoptères	Hydopsychidae	*Hydropsyche* sp.	+		+		+	**
		Leptoceridae	*Oecetis* sp.	+		+			**
			Trianodes sp.	+					*
		Philopotamidae	*Chimarra* sp.	+		+			**
	Diptera	Athericidae	*Atherix* sp.		+	+			*
		Culicidae	*Culex* sp.					+	*
		Chironomidae	*Ablabesmyia* sp.		+			+	**
			Chironomus sp.	+	+	+	+	+	***
			Cryptochironomus sp.	+	+	+	+	+	***
			Polypedilum sp.		+	+	+	+	***
			Stictochironomus sp.	+		+	+	+	**
		Tabanidae	*Tabanus* sp.				+	+	*
		Tipulidae	*Limnophila* sp.		+				*
		Syrphidae	*Siphon* sp.		+			+	*
		Muscidae	Ind.		+				*
		Psychodidae	Ind.					+	*
		Sciomyzidae	Ind.					+	*
	Lepidoptera	Pyralidae	Ind.			+			*
Arachnida	Araneae	Dictynidae	*Argyroneta* sp.	+	+	+		+	***
6	15	54	103	71	51	61	49	73	

+= present taxa, *= accessory taxa; **= common taxa; ***= frequents taxa, F: Taxonomic frequent. Ind. = undetermined, MB: M'Basso; MA: Manzan; YY1: Yèrè Yèrè1; AB: Abradinou; PB: Pont Bettié



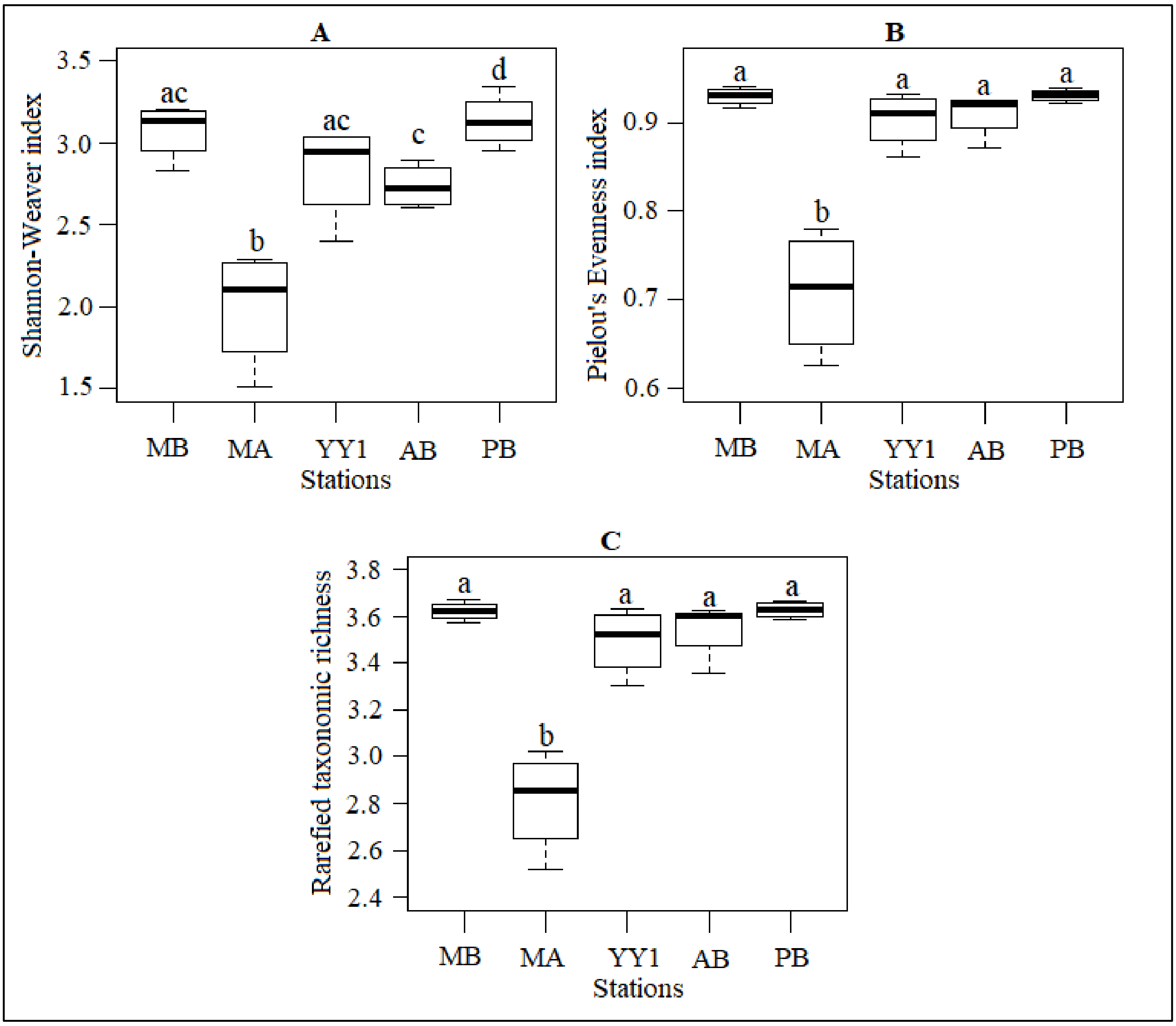
A = abundance at class level; B=Insecta orders abundance; C=Gastropoda orders, Bivalvia orders, and Malacostraca orders abundance.

Figure 2 Spatial distribution of aquatic macroinvertebrates abundance harvested in the middle catchment of Comoé River from March 2021 to March 2022

3.2. Macroinvertebrate community structure

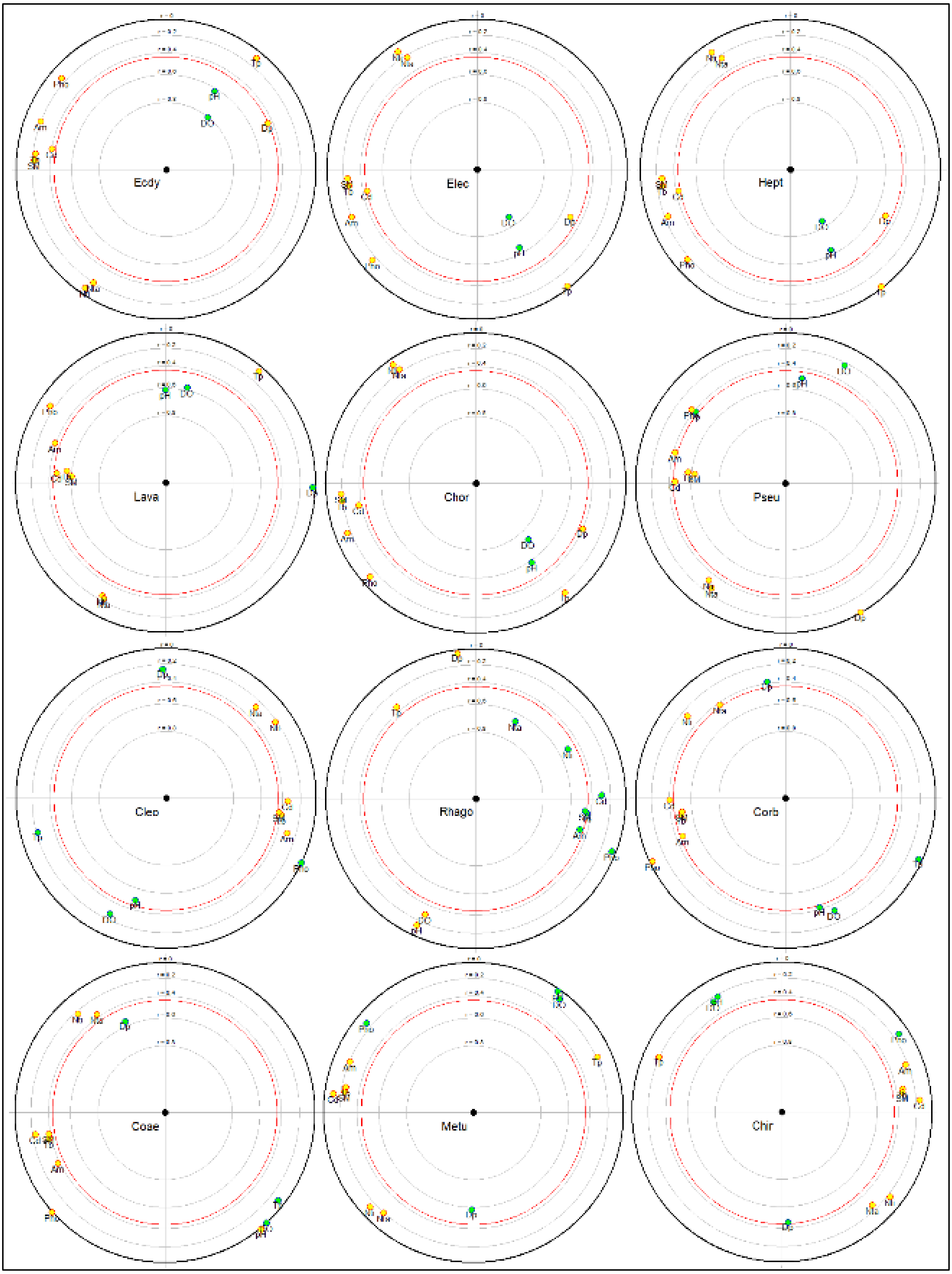
3.2.1. Composition of aquatics macroinvertebrates

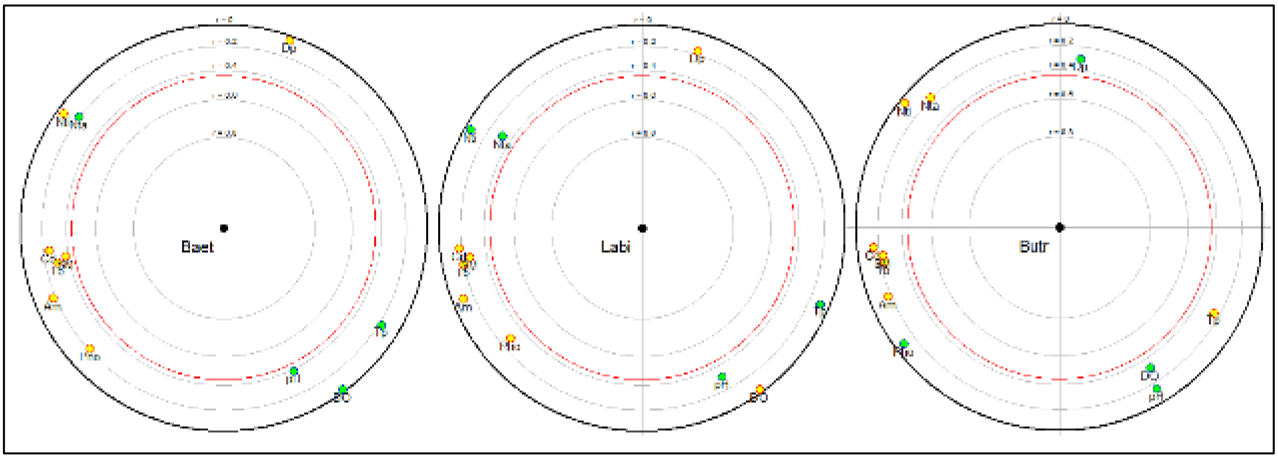
A total of 8547 individuals from 6 classes (Clitellata, Gastropoda, Bivalvia, Malacostraca, Insecta and Arachnida), 15 orders, 54 families and 103 taxa were identified from the stations (Table 3). Aquatic Insecta was the most important group following by Gastropoda, Malacostraca, Bivalvia, Arachnida and Clitellata. Heteroptera had the highest number of taxa (21) followed by Ephemeroptera (17 taxa), Coleoptera (16 taxa), Odonata (15 taxa), and Diptera (10 taxa). Taxonomic richness was highest in Pont Bettié station (73 taxa), M'Basso station (71 taxa), and Yèrè Yèrè1 station (61 taxa) and lowest in Manzan station (51 taxa) and Abradinou station (49 taxa) (Table 3). Rarefied taxonomic richness was significantly lowest in Manzan station than other stations (Figure 3C). Almost 46.30% of taxa were rare, 33.55% and 23.15% accessory (Table 3). Insecta and Gastropoda were the most dominant orders at all stations (Figure 2A). Among Insecta, Ephemeroptera was the most abundant in M'Basso station (1,505 individuals e.g. 71.12%) and Yèrè Yèrè1 station (591 individuals e.g. 44.24%). Whereas, Heteroptera was abundant in Manzan station (499 individuals e.g. 82.75%) and Diptera was highest with in Pont Bettié station (429 individuals e.g. 37.21%) (Figure 2B). Mesogastropoda was the most abundant in all stations except in Manzan station (Figure 2C). Both the Shannon-Weaver index and Pielou Evenness index showed a lowest value in Manzan station (1.5 and 0.62) and statistically different from the other stations (Figure 3A, 3B). Pont Bettié station exhibited the significant highest Shannon-Weaver diversity value (3.33) while Abradinou station and Yèrè Yèrè1 station did not show differences (Figure 3). The proportion of ETP decrease from M'Basso station (59.77%) to Manzan station (6.27%).



MB = M'Basso station, MA = Manzan station, YY1 = Yèrè Yèrè1 station, AB = Abradinou station and PB = Pont Bettié station. Different letters (a and b) on box-plots significant difference between them (Mann-Whitney, *p<0,05*)

Figure 3 Spatial variation of Shannon-Weaver index (A), Pielou evenness index (B), and rarefied taxonomic index (C) of the middle catchment of Comoé River:


Ecdy
Elec
Hept
Lava
Chor
Pseu
Cleo
Rhago
Corb
Coae
Melu
Chir



Taxa: Ecdy: *Ecdyonurus* sp.; Elec: *Electrogena* sp.; Hept: *Heptagenia* sp.; Lava: *Lanistes varicus*; Chor *Choroterpes* sp.; Pseu: *Pseudagrion* sp.; Cleo: *Cleopatra* sp.; Rhago: *Rhagovelia* sp.; Corb: *Corbula* sp.; Coae: *Coelatura aegyptiaca*; Metu: *Melanoides tuberculata*; Chir: *Chironomus* sp.; Baet: *Baetis* sp.; Labi: *Labiobaetis* sp.; Butr: *Bulinus troncatus*; Environmental variables: Tp: water temperature; Dp: water depth; pH: Hydrogen potential; DO: Dissolved Oxygen; Tb: Turbidity; Cd: Conductivity; Nti: Nitrite; Nta: Nitrate; Am: Ammonium; Pho: Phosphate; SM: Suspended Matter.

Figure 4 Focused principal component analysis showing the correlation between environmental variables and the taxa of the middle catchment of Comoé River

3.3. Taxa relationships with environmental variables

For this analysis, FPCA showed correlations between pH and dissolved oxygen. Also, there was correlation between turbidity, conductivity and suspended matter, as well as correlation between nitrite and nitrate. Moreover, the FPCA revealed correlations between taxa retained and environmental variables, indicated by a red circle for significant correlations (Figure 4). *Ecdyonurus* sp., *Electrogena* sp., and *Heptagenia* sp. were positively and significantly influenced by pH and dissolved oxygen, but strongly and negatively correlated with water depth. *Lanistes varicus* was positively and significantly influenced ($p<0.05$) by pH and dissolved oxygen and negatively correlated with conductivity, turbidity and suspended matter. *Choroterpes* sp. was only positively influenced by pH and dissolved oxygen. *Pseudagrion* sp. was strongly and positively correlated with pH (red circle), but strongly and negatively correlated with conductivity, suspended matter and turbidity. *Cleopatra* sp. was positively influenced by pH. *Rhagovelia* sp. was positively correlated with nitrite, nitrate, ammonium suspended matter and turbidity. *Coelatura aegyptiaca*, *Melanoides tuberculata* and *Chironomus* sp. were positively influenced by water depth. *Corbula* sp. was negatively correlated with suspended matter, turbidity and ammonium. In contrast, *Bulinus troncatus*, *Baetis* sp. and *Labiobaetis* sp., were not influenced by environmental variables.

4. Discussion

The findings of this study revealed that environmental variables in the middle catchment of Comoé River, particularly at station located on tributary and those of downstream of the confluence, reflected significant ecological degradation attributable to human activities. Stations such as Manzan and Abradinou exhibited characteristics of low water quality influenced by artisanal gold mining and extensive agricultural activities such as rubber, banana and cocoa plantations. These land-use practices contributed substantially to elevated levels of suspended matter, turbidity, and conductivity, thereby negatively impacting water quality of stations located after confluence zone.

In particular, exceptionally high concentrations of suspended matter in Manzan station, could be due to sediment washing during artisanal gold mining operations. Gold miners disturb the riverbed, releasing clay, silt and other particulates into the water column. Similar processes occur in Abradinou station, where suspended matter are also high, due to local sand extraction activities. Turbidity levels in Manzan station were also extremely high (997-2355 NTU), surpassing those reported by Ayiwouo *et al.* [62] for the Lom River (117-510 NTU). According to Kilonzo *et al.* [63] the highest turbidity values could be attributed not only to mining but also to soil erosion from agricultural slopes and unpaved roads. These disturbances introduce both organic and inorganic particulates into the water, further degrading water clarity [64]. These high values (turbidity and suspended solids) were attributed to artisanal and semi-mechanized exploitation, which through the various activities carried out, such as deforestation, digging in the riverbed, or even the exposure of washing discharges, contribute to their increase [65]. Additionally, mining induced acid drainage can release metal ions, which contribute to the elevated conductivity observed in Manzan station. Dissolved oxygen (DO) concentrations recorded in M'Basso was because this station is relatively less impacted by anthropogenic stressors.

Low DO levels in Manzan station are consistent with heavy human disturbances, including mining, agricultural runoff, and domestic waste discharge.

Aquatic macroinvertebrates analysis revealed a total of 103 taxa, a richness higher than that reported in the lower part of Comoé River (97 taxa) [32], Bia River (81 taxa) [66] and Agnéby River (50 taxa) [67]. But this number of taxa is lower than those obtained by Camara [68] in Banco River (132 taxa) and Edia *et al.* [52] in mountainous rivers of southeast Guinea (129 taxa)). These discrepancies in taxonomic richness are likely influenced by sampling protocols, habitat diversity, sampling effort and equipment used. For instance, this study employed four sampling campaigns across five stations using kick net, Van Veen grab and artificial substrates. In contrast, Camara *et al.* [69] conducted monthly samplings over two years with additional tools like the Ekman grab and sieves. These methodological differences justify the observed variations in macroinvertebrate richness.

Insecta emerged as the dominant class, accounting for 84 of the 103 identified taxa. Insects are widely recognized as the most diverse group of freshwater macroinvertebrates [70], a trend confirmed by other studies [71, 69, 52]. This dominance reflects the adaptability of aquatic insects to various microhabitats and their sensitivity to ecological conditions, making them excellent bioindicators.

Biodiversity indices also highlighted ecological disparities among the stations. Shannon-Weaver diversity index, Pielou evenness index and rarefied richness values were highest in Pont Bettié station and M'Basso station, indicating well-structured and balanced communities. In contrast, Manzan station exhibited the lowest values, reflecting a simplified community structure likely resulting from intense anthropogenic pressures [72]. According to Arimoro and Ikomi [73], high species diversity in these water bodies are associated with un-impacted or unpolluted conditions.

The proportion of EPT taxa (Ephemeroptera, Plecoptera, and Trichoptera) was notably high in M'Basso station and Yèrè Yèrè1 station, suggesting good water quality, while other stations particularly Manzan station showed reduced EPT presence. EPT taxa thrive in well-oxygenated environments, and their abundance in M'Basso station positioned upstream of the confluence zone qualified as a reference station. As emphasized by Moisan and Pelletier [74], such sites are characterized by high EPT diversity. Habitat features like gravel beds, rocks, and submerged vegetation in M'Basso promote macroinvertebrate colonization and abundance [25, 26]. Similarly, the proximity of Yèrè Yèrè1 to M'Basso could explain its elevated EPT values, due to less degraded upstream influences.

The FPCA analyses reveal significant relationships ($p<0.05$) between aquatic macroinvertebrates and environmental variables in the middle catchment of Comoé River. Results from FPCA further indicated that pH and DO favour the abundance of sensitive taxa such as *Ecdyonurus* sp., *Electrogena* sp., and *Heptagenia* sp. [67]. These taxa were more prevalent in shallower, oxygen areas such as M'Basso station. In contrast, species like *Melanoides tuberculata*, *Coelatura aegyptiaca* and *Chironomus* sp. thrived in deeper, disturbed environments such as Pont Bettié station, underlining the ecological significance of water depth. High turbidity and suspended matter levels had a deleterious effect on sensitive taxa such as *Lanistes varicus* and *Corbula* sp. In contrast, pollution-tolerant species like *Rhagovelia sp.* were more abundant in areas with elevated nutrient concentration (nitrite, nitrate, ammonium), turbidity, and suspended matter particularly in Manzan station. Some macroinvertebrates exhibited strong correlations with specific environmental variables, suggesting adaptation to distinct habitats [59]. Prevalence of *Pseudagrion* sp. in less turbid, low-mineralized waters highlights the impact of water clarity on Odonata distributions. These findings have important implications for ecological studies [75, 76]. Macroinvertebrates exhibit distinct community patterns across different habitats, indicating sensitivity to changes in water quality, habitat structure and other ecological factors [77]. Environmental gradients, such as water chemistry and physical characteristics, shape macroinvertebrate community composition [78]. For instance, *Bulinus globosus* is well-suited to alkaline environments with high pH levels [79], whereas *Chironomus* sp. demonstrates remarkable tolerance to diverse water chemistry conditions [80].

5. Conclusion

The middle catchment of Comoé River is subject to artisanal gold mining and land degradation which have an impact on the downstream of the river. Analysis environmental variables have enabled us to characterize the waters of Manzan River, which are highly mineralized, turbid and heavily laden with suspended matter. Indices of diversity, composition and abundance of aquatic macroinvertebrates showed that Abradinou station and Manzan station are the most impacted by human activities in the middle of Comoé River. ETP index showed relatively good quality waters in M'Basso and Yèrè Yèrè1 stations, while the other stations are of poor ecological quality. FPCA analysis showed that environmental variables influence aquatic organisms, particularly aquatic macroinvertebrates.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Meyer WB, Turner BL. Changes in Land Use and Land Cover: A Global Perspective. New York: Cambridge Univ. Press. 1994 ; 537.

[2] Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Lévêque C. Freshwater biodiversity: importance, threats, status and conservation challenges. Biol. Rev. 2006 ; 81 (2) : 163-182.

[3] Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PT. Emerging threats and persistent conservation challenges for freshwater biodiversity. Biol. Rev. 2019 ; 94 (3) : 849-873.

[4] Meyer JL, Sale MJ, Mulholland PJ, Poff NL. Impacts of climate change on aquatic. 1999.

[5] Scott MC, Helfman GS. Native invasions, homogenization, and the mismeasure of integrity of fish assemblages. Fisheries. 2001 ; 26 : 6-15.

[6] Nilsson C, Berggren K. Alterations of riparian ecosystems caused by river regulation. BioScience. 2000 ; 50 : 783-92.

[7] FAO. The State of Food Insecurity in the World: the Multiple Dimensions of Food Security ; 2013.

[8] Yapi YHA, Dongui BK, Trokourey A, Barima YSS, Essis Y, Atheba. Assessment of metal pollution of groundwater and surface water in a gold mining environment in Hiré (Côte d'Ivoire). International journal of biological and chemical sciences Sci. 2014; 8: 1281-1289.

[9] Bamba O, Souleymane P, Sako A, Kagambega N, Miningou MYW. "Impact of artisanal mining on the soils of a developed agricultural environment in Burkina Faso". 2013; 13: 12.

[10] CNRA. The National Center for Agronomic Research in 2012. We are inventing the agriculture of tomorrow today. 2013, http://www.cnra.ci/publi.php. Accessed 25 Jan 2015.

[11] Ruf F. The adoption of rubber cultivation in Côte d'Ivoire Price, imitation and ecological change. Session: Innovation in family farming and public policies. The case of rubber cultivation. 3rd research days in social sciences. INRA-SFER-CIRAD, Montpellier, France. 2009; 3013: 27367

[12] Allen K, Corre MD, Tjoa A, Veldkamp E. Soil nitrogen-cycling responses to conversion of lowland forests to oil palm and rubber plantations in Sumatra, Indonesia. PLoS ONE ; 2015.

[13] McDowell RW, Sharpley AN. Approximating phosphorus release from soils to surface runoff and subsurface drainage. J. Environ. Qual. 2001 ; 30 (2) : 508-520.

[14] Osano O, Nzyuko D, Admiraal W. The fate of chloroacetalinide herbicides and their degradation products in the Nzoia Basin. Kenya. Ambio. 2003 ; 32 : 424-427.

[15] Burdon FJ, McIntosh AR, Harding JS. Habitat loss drives threshold response of benthic invertebrate communities to deposited sediment in agricultural streams. Ecol. Appl. 2013; 23(5) : 1036-1047.

[16] Hilson G, Hilson A, Maconachie R, McQuilken J, Goumandakoye H. Artisanal and Small-Scale Mining (ASM) in Sub-Saharan Africa: Re-Conceptualizing Formalization and 'Illegal' Activity. Geoforum. 2017 ; 83 : 80-90.

[17] Machaček J. Alluvial Artisanal and Small-Scale Mining in A River Stream-Rutsiro Case Study (Rwanda). 2020 ; 24.

[18] World Health Organization. Environmental and occupational health hazards associated with artisanal and small-scale gold mining. 2017.

[19] Dold B. Evolution of Acid Mine Drainage Formation in Sulphidic Mine Tailings. 2014 ; 4 : 621-641.

[20] Loayza-Muro RA, Elías-Letts R, Marticorena-Ruíz JK, Palomino EJ, Duivenvoorden JF, Kraak MH, Admiraal W. Metal-induced shifts in benthic macroinvertebrate community composition in Andean high altitude streams. Environ. Toxicol. Chem. 2010 ; 29 : 2761-2768.

[21] Graco-Roza C, Santos JB, Huszar VL, Domingos P, Soininen J, Marinho MM. Downstream transport processes modulate the effects of environmental heterogeneity on riverine phytoplankton. Sci. Total Environ. 2020 ; 703 : 135-519

[22] Altarriba EL, Heyer-Rodríguez L, Rábago-Castro JL, Vázquez-Sauceda ML, Pérez-Castaneda R, Arellano-Méndez LU. Toxicity of river water polluted by urban wastewater to aquatic organisms. Toxicol. Lett. 2016 ; 259 : 127-128.

[23] Dou P, Wang X, Lan Y, Cui B, Bai J, Xie T. Benthic Macroinvertebrate Diversity as Affected by the Construction of Inland Waterways along Montane Stretches of Two Rivers in China. Water. 2022 ; 14: 1080.

[24] Ngom NM, Mbaye M, Baratoux D, Baratoux L, Ahoussi KE, Kouame JK, Faye G, Sow El H. Recent expansion of artisanal gold mining along the Bandama River (Côte d'Ivoire). International Journal of Applied Earth Observations and Geoinformation. 2022 ;16.

[25] Mwaijengo GN, Vanschoenwinkel B, Dube T, Njau KN, Brendonck L. Seasonal variation in benthic macroinvertebrate assemblages and water quality in an Afrotropical River catchment, north-eastern Tanzania. Limnological. 2020 ; 82 : 125-780.

[26] Amorino K, Szarek-Gwiazda E. The Impact of Pollution on Diversity and Density of Benthic Macroinvertebrates in Mountain and Upland Rivers. Water. 2022 ; 14 : 1349.

[27] Cummins KW. Trophic relations of aquatic insects. Annu. Rev. Entomol. 1973 ; 18 (1) : 183-206.

[28] Jiang X, Pan B, Jiang W, Hou Y, Yang H, Zhu P, Heino J. The role of environmental conditions, climatic factors and spatial processes in driving multiple facets of stream macroinvertebrate beta diversity in a climatically heterogeneous mountain region. Ecol. Indic. 2021 ; 124 : 107-407.

[29] Barbour MT, Gerritsen J, Snyder BD, Stribling JB. Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish. Environmental Protection Agency. 1999 ; 841 : 99-002.

[30] Woodcock TS, Huryn AD. The response of macroinvertebrate production to a pollution gradient in a headwater stream. Freshwater Biology. 2007 ; 52 : 177-196.

[31] Sankaré Y. Comparative study of the macrofauna associated with the roots of Pistia stratiotes L. (Araceae) of the Ayamé II dam lake and the Comoé River (Côte d'Ivoire). Ivorian Journal of Oceanology and Limnology. 1991; 1(2): 131-138.

[32] Kra MK, Camara IA, Edia EO, Konan MK, Diomandé D, Ouattara A. Qualitative analysis of aquatic macroinvertebrates in lower comoe river (Côte d'Ivoire). International Journal of Fisheries and Aquatic Studies. 2018 ; 6 (2) : 472-481

[33] Bamba Y, Kamagaté M, Berté S, Komoé K. Spatial diversity and distribution of Aquatic Macroinvertebrates in the middle course of the Comoé River (Ivory Coast, West Africa). International Journal of Innovation and Applied Studies. 2023; 40 : 1200-1213.

[34] Moro AP, Kouakou NKP, Diarassouba M, Adou BYC, Konan D, Koffi A, Kouakou TH, Obouayeba S. Influence of Downward Tapping Delay on Agronomic Parameters of Upward Tapping Rubber Trees. Asian Research Journal of Agriculture. 2021 ;14(4): 63-75

[35] [35] PEMED-CI. Monographic and economic studies of the Districts of Côte d'Ivoire. 2015.

[36] APHA. Standard methods for the examination of water and wastewater 20th edition. American Public Health Association, American Water Work Association, Water Environment Federation, Washington DC. 1998.

[37] Wilson JG, Dunne N, Giltrap M. Assessing candidate metrics for the ecological quality of TFTW (tidal freshwaters in transitional waters) in Ireland using benthic invertebrates, Ocean & Coastal Management. 2017.

[38] Déjoux C, Elouard JM, Forge P, Malsin J. Iconographic catalogue of aquatic insects of Ivory Coast. ORSTOM report. Bouaké, Côte d'Ivoire; 1981.p. 172.

[39] Day JA, Stewart BA, de Moor IJ Guide to the Freshwater Invertebrates of Southern African. Volume 4: Crustacé III: Bathynellacea, Amphipoda, Isopode, Spelaeogriphacea, Tanaidacea, Décapode. Rapport N TT 141/01 Water Research Commission, South African; 2001.p. 141.

[40] Day JA, Stewart BA, de Moor IJ. Guide to the Freshwater Invertebrates of Southern African. Volume 9: Diptera. Rapport N TT 201/02 Water Research Commission, South African; 2003.p. 200.

[41] Stals R, De Moor IJ. Guides to the Freshwater Invertebrates of Southern African. Volume 10: Coleoptera. Rapport N TT 320/07 Water Research Commission, South African. 2007 ; 263.

[42] Tachet H, Richoux P, Bournaud M, Usseglio-Polatera P. Freshwater invertebrates: systematics, biology, ecology, new revised and expanded edition, Paris, CNRS Editions. 2010; 607.

[43] Powell CB. The genus Macrobrachium in West Africa. I: M. thysi, a new large – egged species from Ivory Coast (Crustacea Decapoda Palaemonidae). Journal of African Zoology. 1980; 94:317-326.

[44] Cumberlidge N. Description of crustacean species collected in northwest Guinea. Washington, DC: Rapid Assessment Program (RAP), Conservation International, Bulletin of Biological Assessment. 2006; 41: 168-175.

[45] Fransen CHJM. Anomurans, Stomatopods, Shrimps and Prawns, True Crabs. In: Carpenter, K. E. & De Angelis, N. (Eds). The living marine resources of the Eastern Central Atlantic. Volume 1: Introduction, crustaceans, chitons, and cephalopods. FAO Species Identification Guide for Fishery Purposes, Rome, FAO. 2014 ; 37-196.

[46] Shannon CE, Weaver W. The mathematical theory of communication. Urbana University Press, Illinois. 1963 ; 127.

[47] Clarke KR, Warwick RM. Change in marine communities An Approach to Statistical Analysis and Interpretation. 2nd Edition. 2001; 176.

[48] McIntosh RP. An index of diversity and the relation of certain concepts to diversity. Ecology. 1967 ; 48(3) : 392-404.

[49] Pielou EC. The interpretation of ecological data. Wiley & Sons, New York. 1984 ; 7.

[50] Gotelli NJ, Ellison AM. A Primer of Ecological Statistics. Sunderland, MA: Sinauer Associates Inc ; 2012.

[51] Heck KLJ, Belle GV, Simberloff D. Explicit calculation of the rarefaction diversity measurement and the determination of sufficient sample size. Ecology. 1975 ; 56: 1459-1461.

[52] Edia OE, Emmanuel C, Konan KM, Gattolliat JL. Diversity, distribution and habitat requirements of aquatic insect communities in tropical mountain streams (South-eastern Guinea, West Africa). International Journal of Limnology. 2016 ; 52 : 285-300.

[53] Oksanen YF, Blanchet G, Kindt, Legendre P, Minci PR, O'hara RB, Gavin L, Simpson, Solymos P, Stevens MHH, Wagner H. "Vegan: Community Ecology Package", Librairie R en ligne. Url: http://CRAN.R-project.org/package = vegan. 2013.

[54] Rosenberg DM, Resh VH. Freshwater Biomonitoring and Benthic Macroinvertebrates. New York: Chapman & Hall. 1993 ; 29.

[55] Dajoz R. Summary of Ecology. Edition, Dunod, Paris. 2000; 615.

[56] Lauzanne L. Diets and trophic relationships of fish in Lake Chad. ORSTOM notebook, Hydrobiology series. 1976; 10: 267-310.

[57] Hyslop EJ. Stomach contents analysis, a review of methods and their application. Journal of Fish Biology. 1980 ; 17: 411-429.

[58] Fossi MC, Baini M, Panti C, Galli M, Jiménez B, Muñoz-Arnanz J, Marsili L, Finoia MG, Ramírez-Macías D. Are whale sharks exposed to persistent organic pollutants and plastic pollution in the Gulf of California (Mexico)? First ecotoxicological investigation using skin biopsies, Comparative Biochemistry and Physiology. 2017 ; 199 : 48-58.

[59] Arimoro FO, James J, Ikayaja EO, Assie FAGJ, Edegbene AO, Keke UN. Dissecting the urban footprint of unplanned settlements shaping macroinvertebrate communities in Wuye River, Abuja, Nigeria. Scientific Reports. 2025 ; 15 :166-15.

[60] Falissard B. "psy: Various Procedures Used in Psychometrics". R package version 1.2, https://CRAN.R-project.org/package=psy ; 2022.

[61] Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens M, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, Chirico M, De Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill M, Lahti L, McGlinn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C, Weedon J. "Vegan: Community Ecology Package". R package version 2.6-8, <https://CRAN.R-project.org/package=vegan>. 2024.

[62] Ayiwouo MN, Yamgouot FN, Mambou LLN, Kingni ST, Ngounouno I. Impact of gold mining on the water quality of the lom river, Gankombol, Cameroon, Heliyon. 2022 ; 8: 124-52.

[63] Kilonzo F, Masese FO, Griensven VA, Bauwens W, Obando J, Lens PNL. Spatial–temporal variability in water quality and macro-invertebrate assemblages in the Upper Mara River basin, Kenya. Phys. Chem. Earth Parts A/B/C. 2014 ; 67 : 93–104.

[64] Ntengwe FW. Pollutant loads and water quality in streams of heavily populated and industrialised towns.Phys. Chem. Earth. 2006 ; 31 : 832-839.

[65] Ngueyep LLM, Takougang KS, Ayiwouo NM, Ndi A A. The impact of gold mining exploitation on the physicochemical quality of water: case of Batouri (Cameroon), International Journal of Energy and Water Resources. 2021 ;15.

[66] Diétoa YM. Entomofauna and feeding strategies of fish of the genus Brycinus (Characidae) in fluvial and lacustrine environments (Bia and Agnéby Basins; Côte d'Ivoire). [Doctoral thesis]. University of Abobo-Adjamé, Côte d'Ivoire; 2002.

[67] Diomandé D, Bony KY, Edia OE, Konan FK, Gourène G. Diversity of benthic macroinvertebrates in the Agnéby River (Côte d'Ivoire; West Africa). European Journal of Scientific Research. 2009; 35(3): 368-377.

[68] Camara AI. Composition, structure and determinism of macroinvertebrates of the Banco River (Banco National Park; Côte d'Ivoire). [Doctoral thesis]. Nangui Abrogoua University, Abidjan; 2013

[69] Camara AI, Diomandé D, Bony YK, Ouattara A, Franquet E, Gourène G. Diversity assessment of benthic macroinvertebrate communities in Banco National Park (Banco Stream, Côte d'Ivoire). *African Journal of Ecomogy*. 2012 ; 50: 205-217.

[70] Gagnon E, Pedneau J. Voluntary Surveillance (SurVol) Benthos, volunteer guide, voluntary monitoring program for small watercourses. CVRB, Quebec, Canada; 2006.

[71] Edia OE, Brosse S, Ouattara A, Gourène G, Winterton P, Lek-Ang S. Aquatic insect assemblage patterns in four West-African coastal rivers. Journal of Biological Sciences. 2007 ; 7 (7) : 1130-1138.

[72] Bisimawa MA. Assessment of the degree of pollution of the Kintama River by the use of benthic macroinvertebrates. International Journal of Innovation and Scientific. 2017; 30: 159-174.

[73] Arimoro FO, Ikomi RB. Ecological integrity of upper Warri River, Niger Delta using aquatic insects as bioindicators. ecological indicators. 2009 ; 8.

[74] Moisan J, Pelletier L. Guide to biological monitoring based on benthic macroinvertebrates in freshwater Quebec, Shallow watercourses with coarse substrate 2008, Environmental Status Monitoring Department, Ministry of Sustainable Development, Environment and Parks; 2008.p. 86.

[75] Ter Braak CJF. Canonical correspondence analysis: a new eigenvector method for multivariate direct gradient analysis. Ecology. 1986 ; 67 : 1167-1179.

[76] De Sousa DNR, Mozeto AA, Carneiro RL, Fadini PS. Electrical conductivity and emerging contaminant as markers of surface freshwater contamination by wastewater. Sci. Total Environ. 2014 ; 484 : 19-26.

[77] Legendre P, Legendre L. Numerical ecology. (Elsevier). 2012 ; 24.

[78] Hamid A, Bhat SU, Jehangir A. Assessment of ecological characteristics of macroinvertebrate communities and their relationship with environmental factors in a stream ecosystem. Chem. Ecol. 2021 ; 37 (9-10) : 746-766.

[79] Brown DS. Freshwater snails of Africa and their medical importance (CRC Press). 1994.

[80] Arimoro FO, Auta YI, Odume ON, Keke UN, Mohammed AZ. Mouthpart deformities in Chironomidae (Diptera) as bioindicators of heavy metals pollution in Shiroro Lake, Niger State, Nigeria. Ecotoxicol. Environ. Saf. 2018 ; 149: 96-100.